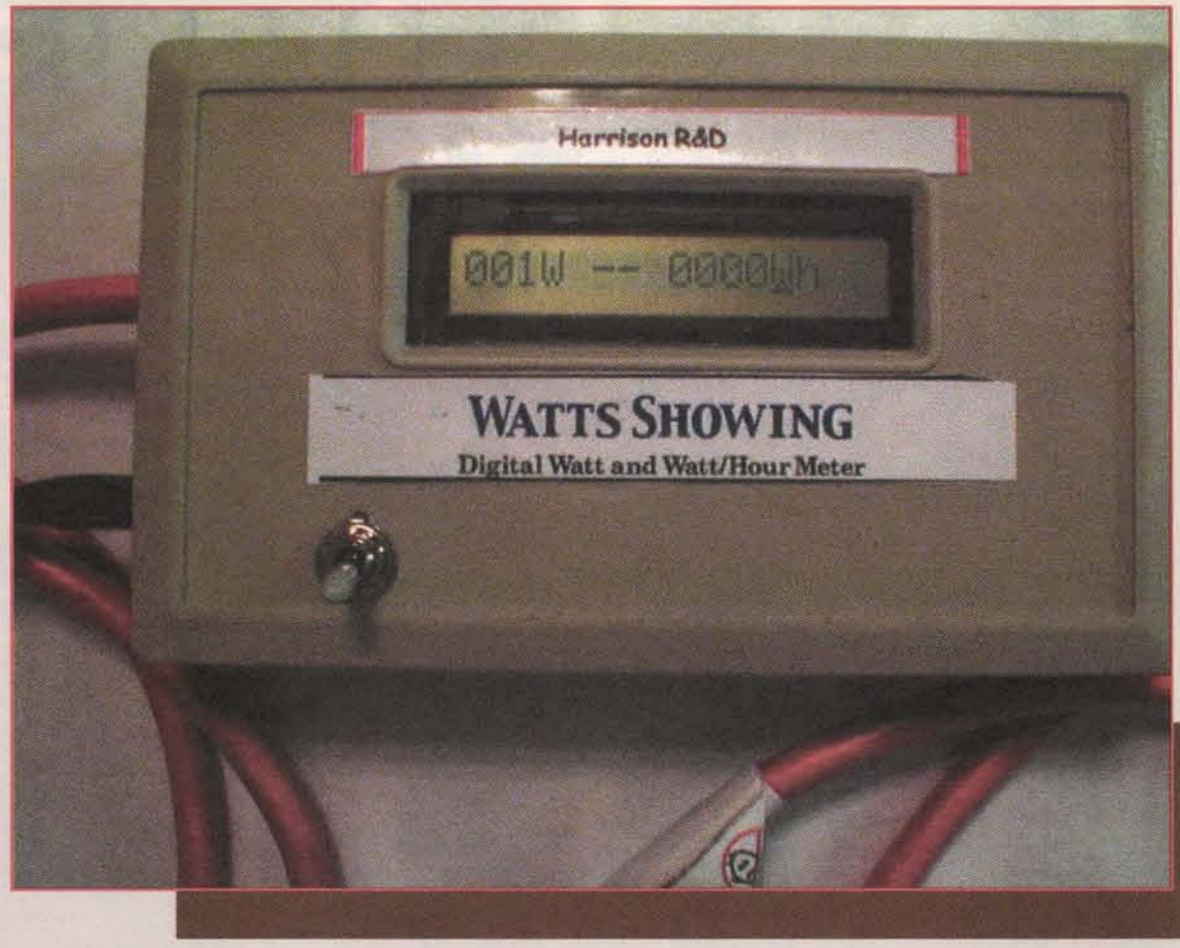
# Build a Digital Watt and Watt-Hour Meter

**by Dan Harrison**

***Have you ever wondered why your electric bill is so high? How much electricity does your freezer, blow dryer, or air conditioner consume? Most people really have no idea how much each appliance costs to operate each year.***




With the 'Watts Showing™,' a digital watt and watt-hour meter kit you can build, data on electrical power consumption can be accurately measured and operating costs calculated on anything that plugs into a 120VAC outlet.

Virtually every house and most apartments in the US are connected to an AC watt-hour meter that the power company or apartment complex uses to measure the amount of electricity consumed. A watt-hour is the equivalent of consuming one watt of power for one hour, or two watts of power for 30 minutes, or six watts of power for 10 minutes, and so on.

Traditional watt-hour meters are electro-mechanical devices, which use a small amount of the electrical power going through it to spin a wheel, which drives clock-like meter dials. I'm sure that everyone reading this magazine has seen them. [An interesting thought. Just like a mechanical clock with moving wheels, the power company's watt-hour meter can be inaccurate, too. How long has it been since the calibration on your meter was checked?]

Watts Showing is an all solid-state digital version of the watt and watt-hour meter with an LCD display. Any standard AC power voltage or frequency (90-240VAC, 50/60Hz) can be accommodated, making the Watts Showing useful around the world.

## Measuring AC Electrical Power

From elementary circuit theory, we know electrical power is the product of voltage times current, P = I x E. For direct current (DC) circuits, power measurements can be made with a simple voltmeter and ammeter. When we get into complex AC circuits, the measurement is not so simple or straightforward.

To understand power measurement in complex circuits, a review of basic Alternating Current (AC) theory is in order.

The electrical power coming into your home has the shape of a sinewave and a frequency of either 50 or 60Hz, depending on where you live. The period for a 60Hz sinewave is P = 1/60 = 16.67ms. In the US, the standard frequency is 60Hz and that will be used for all calculations in this article.

A sinewave and its characteristics are shown in Figure 1. The amplitude of a sinewave is constantly changing with time, so when we refer to an AC voltage, we need to define whether it's the peak value or the RMS value we're speaking of. The peak value is the most distant displacement from the zero line, either positive or negative in a true sinewave. The Root-Mean-Square, or RMS, value is the value that you would read on an AC voltmeter. The RMS value is always .707 of the peak value for sinewaves. Why .707 times the peak value and not 50% instead?

The reason is that a sinewave completes a full cycle in 360 degrees. In each 90-degree quadrant (4 x 90 = 360), the voltage changes by the delta of Vpeak; quadrant 1 is 0V to Vpeak, quadrant 2 is Vpeak to 0V, quadrant 3 is 0V to -Vpeak, and quadrant 4 is -Vpeak to 0V. Knowing that each quadrant is 90 degrees 'long' in angular displacement, then 50% of the rotation is 45 degrees. If you think that half way through the rotation of each quadrant would be the average, or effective voltage you're right! It's the sin (45 deg.), .707, times the Vpeak that we use for RMS voltage.

RMS is the DC equivalent in terms of calculations for power. In other words, a 115VAC (RMS) source driving a 100-ohm load would produce the same power as a 115VDC source driving a 100-ohm load. For a voltmeter (RMS) reading of 115VAC, the actual peak voltage is 162.6V and the peak-to-peak value is 325.2V.

Example: Assume a trivial case of delivering power to a resistive load like an incandescent light bulb. We assume the bulb is rated at 60 watts with nominal 120VAC power input. Given the formula P = I x V and using a little algebra, we can determine that current (I) equals P/V, which is 0.5amp in the case of a nominal 120VAC source. In the resistive case (P) power, is the product of IRms and VRms.

Figure 2 illustrates the relationship of voltage and current in a resistive circuit. We know from basic circuit theory that when inductance and/or capacitance is added to an AC circuit, the phase relationship between current and voltage changes, making measurement of power consumption more difficult. Now it becomes necessary to sum the instantaneous product of voltage and current over time to calculate actual, or real, power.

When RMS voltage and RMS current are multiplied, it is called Apparent Power. This is what you would get, for example, when you use a clamp-on ammeter to measure air conditioner compressor current and multiply that number by the operating voltage to determine power consumption. The number you calculate is not real power, it's apparent power.

It's critical to understand that power cannot be accurately determined by multiplying RMS current by RMS voltage due to the phase difference that exists in a non-resistive AC circuit. This can best be illustrated by the perfect circuit which only contains an inductor and assumes zero resistance in the wires, see Figure 3a. In a purely inductive circuit, current is said to *lag* the voltage by 90 degrees. The voltage leads the current because it depends on the rate of change of current through the inductor, and inductors resist a change in current flow. This is explained as follows.

At some instant in time, the current will equal zero and will begin to increase in value. When the current is increasing — in the first 90-degree quadrant — the counter electromotive force of the inductor opposes the applied voltage and energy is expended countering this force. During the second 90-degree quadrant, the current begins to decrease from its peak value and voltage is again induced in the inductor, but this time energy is added in the same quantity that was used opposing the voltage. Averaging this power results in a zero net power consumed even though large currents and voltages would be measured!

In the real world, nothing is perfect though, and the electrical resistance of the wires will have the effect of reducing the angle of lag. Let's assume that the inductor has a resistance of 10 ohms and an inductance of 100 Mh. See Figure 3b. The impedance of the inductor at 60Hz is about 38 ohms. To determine current, we find the total impedance

$$Z = \sqrt{R^2 + XL^2} = \sqrt{10^2 + 38^2} = 39.2\Omega$$

The phase angle is

$$\theta = \frac{XL}{R} = \frac{38}{10} = 75.25^0$$

The value of the current would be

$$I_t = \frac{V}{Z} = \frac{120V}{39.2} = 3.06A$$

giving an apparent power of 367 watts. Only the power dissipated by the resistance is true power and it is determined by

$P = I^2R = 3.06^2*10 = 93.6W$

or

$P = \cos\theta(EI) = 96.3W.$

Remember, in an inductive circuit, true power is always less than apparent power. The ratio of true power to apparent power is called the Power Factor. In the example shown, the power factor would equal

$\frac{P_{true}}{P_{app}} = .255.$

Watts Showing uses an analog quadrature multiplier, actually a Gilbert Cell derivative, to calculate true power. This circuit continuously produces the product of instantaneous voltage and current.

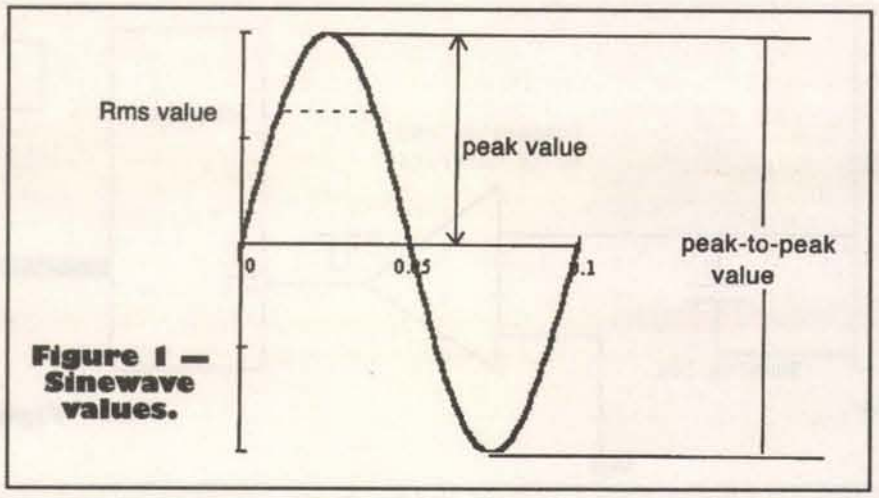



**Figure 1 — Sinewave values.**

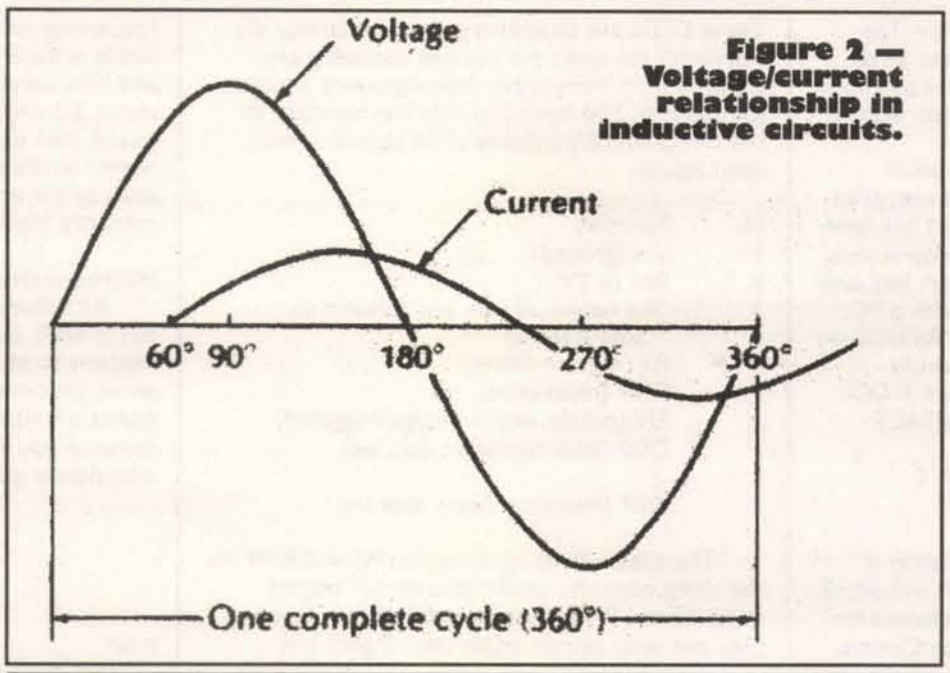



**Figure 2 — Voltage/current relationship in inductive circuits.**

## How It Works

The Watts Showing's four main functional blocks are (Figure 4): the optically-isolated AC current and voltage measurement, the quadrature multiplier and summer circuit, the MC68HC705P6 microprocessor, and the LCD display. All four blocks are contained on two circuit boards and housed in a single assembly.

### Optically-Isolated AC Current and Voltage Measurement

Refer to the schematic in Figure 5 for the following description. The current and voltage measurement is composed of R1, POT1, Shunt1, and half of U1 (the LEDs). When an AC voltage is applied to the AC input terminals, current flows through either the D1-D3 pair or the D2-D4 pair, depending on the polarity of the voltage. In the no-load case, current flow through all diodes is equal since no voltage is dropped across the shunt, S1. When a load is applied to the AC output, there is a voltage drop across the shunt and slightly less current will flow in D3 and D4 than D1 and D2. The decrease in current flow makes a small change in the light output also. The amount of light output is therefore dependent on both voltage and current (remember that the product of voltage and current is power) at any given time.

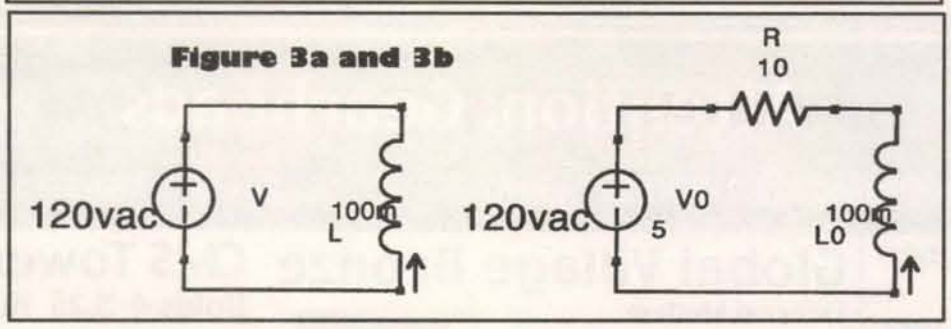



**Figure 3a and 3b**

The 500k ohm pot (Pot2) in series with R1, is used to control the bias current through the LEDs in the optocoupler. This bias current sets the rate of discharge of C1, which determines the scaling factor of the watt meter. As the voltage across the shunt increases, it results in a lower voltage across D3, D4, Pot2, and R1. This means less current flow, and lower light output as the power being measured increases. For 220-240VAC operation, R1 and POT1 values must be changed. I've never operated this circuit above 120VAC so, while it should work, I can't say exactly what value resistors will be needed to keep the watt measurement correct.

### Quadrature Multiplier and Summing Circuit

The multiplier and summer are made up of all the components inside the dashed block on the schematic. The transistors in U3 form two stacked differential amplifiers, in a modified Gilbert Cell arrangement. The output is proportional to the difference in light output from the LEDs, which we remember is a product of voltage and current (power). This is fed into C1 where it accumulates (sums).

When the voltage on C1 goes below the threshold set by Pot1 (approximately 0.4V, depending on capacitor and resistor tolerances), the output of U2A, pin 1, goes high. This, in turn, takes the inverting input of U2b to a high state, forcing the output, pin 7, to go low. This results in Q1 being turned on which charges the capacitor, C1 through R2.

When the voltage on C1 again crosses the threshold going positive, set by Pot1, U2a will switch back to a low output, driving U2b back to a high output and turning off Q1 which stops charging C1. The values shown will produce a 1-pulse/joule, which is 1Hz/watt. The output pulse width is set to approximately 400uS.

This configuration allows a full-scale measurement of greater than 1,000 watts. One thing to keep in mind about this circuit is the stacked differential amplifiers are extremely sensitive and must be precisely balanced in terms of gain across the four transistors. The gain, or Beta, of a transistor will vary with temperature. So long as all transistors are at the same temperature, the temperature coefficient of the copper shunt helps to cancel out a change in transistor gain as temperature changes. Where you can run into a problem is when a temperature gradient exists across OPT1 and not all transistors are the same temperature. This condition results in erroneous readings and makes it impossible to calibrate. Believe me, I learned this the hard way. Always keep OPT1 away from air currents or heat sources when calibrating.

### The MC68HC705P6

As is true with all microcontrollers, there are two parts to this story: hardware and software. First, a discussion of the hardware configuration will be presented, followed by a description of the software that makes it all work.

#### Microcontroller Hardware

The Motorola MC68HC705P6 is an EPROM version of the MC68HC05P6 microcontroller. It is a low-cost combination of a generic 68HC05 CPU with a 16-bit timer, 176 bytes RAM, 4672 bytes EPROM, and 21 general-purpose I/O lines. A block diagram is shown in Figure 6.

The output pulses from the quadrature multiplier and summing circuit are input to the interrupt pin on the microprocessor. The processor can use this to count the number of pulses and, because it's on an interrupt, the counting process can occur in the background without constant attention from the main program. The interrupt pin must be programmed to be edge-sensitive rather than level-sensitive. Since the pulses generated by the summing circuit are 400uS wide, a level sensitive interrupt will cause the processor to be interrupted many times during the pulse.

The clock generation consists of a 4.00MHz crystal, two 22pF caps, and an 8.2 meg resistor. It's important to include R3 in the clock circuit if you're building this from scratch. This small amount of load helps to get the internal oscillator started; without it you may have trouble getting the processor to operate. The same is true for the Power On Reset circuit (POR), consisting of C6 and R13. The power on reset must be long enough for the crystal and power supply to stabilize. The

```
*************************************************************
* put the LCD cursor in the position specified by
* the contents of ACC
* lcd map 80 81 82 83 84 85 86 87 C0 C1 C2 C3 C4 C5 C6 C7
*
*************************************************************
put_cursor      ;acc=cursor position 0-15
        add     #$80        ;add offset to get address
        cmp     #$88        ;if >88 then add 38h
        blo     do_cursor
        add     #$38
do_cursor
        jsr  put_ctrl       ;write character address to LCD control reg.
        rts
```

**Listing 1. Put_Cursor**

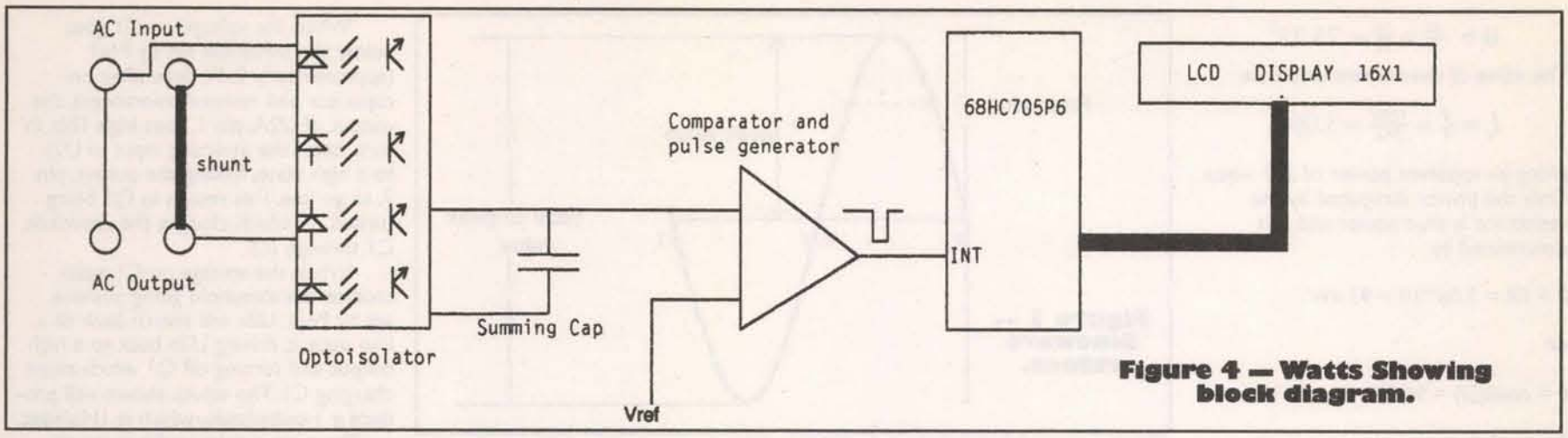



**Figure 4 — Watts Showing block diagram.**

values shown work well over temperature. The LCD interface is straightforward and uses 11 of the processor's general-purpose I/O lines to implement the data/control path. The serial data output PC0 is for serial data out.

Since the MC68HC705P6 has no built-in UART, and we want this design to be as cost-effective as possible, a "bit-banged" serial port has been implemented in software. This port is programmed to be 9600 baud, eight data bits, two start bits, and no parity. If you want to use this port with a PC, the interface needs to be converted to RS232C or RS422, whichever suits your needs. A sample RS232 interface circuit is shown in Figure 7. DO NOT CONNECT TO AN RS232 INTERFACE WITHOUT THE PROPER CIRCUIT.

## LCD Interface

A 16-character-by-one-row LCD display is interfaced to the processor using portA and portB through J1, a 14-pin header. The LCD selected for the interface is a DMC-16117A made by Optrex. These LCDs are an industry standard; similar displays with the exact pin out and mounting are available from many other manufacturers. It sells for about $12.00 from Digi-Key. The interface to the DMC-16117A consists of 14 signals, as outlined below.

| Pin | Function |
|---|---|
| 1 | Vss (ground) |
| 2 | Vcc (+ 5V) |
| 3 | Vee (wiper of a 5k pot connect to pins 1 and 2) |
| 4 | RS (register select) |
| 5 | R/W (read/write) |
| 6 | EN (enable, negative-edge triggered) |
| 7 | DB0 (least-significant data bit) |
| \| | \| |
| 4 | DB7 (most-significant data bit) |

The enable (EN) signal latches RS and R/W on the rising edge and clocks data on the trailing edge. RS and R/W must be stable before E goes high and must remain stable until E goes low (observing set-up and hold times). Data must be stable while E goes low (again, observing set-up and hold times). Power consumption should be about 2-3mA. If you're building this without the PC board, then care should be taken when connecting power to the LCD. Reversing +5V and GND will destroy the unit. Read your data sheet carefully to correctly identify pins 1 and 2.

### Microcontroller Software

All software for the Watts Showing was written in 6805 assembly language. Assembly language happens to be my language of choice for the '05 series processors. At least one software company makes a limited 'C' compiler for this processor for those of you who prefer 'C.' The software overview is outlined in the following pseudo-code:

```
                Power-on Reset
                Initialize processor I/O, timers,
                  and A/D
                Initialize LCD display
main            Print start-up message
```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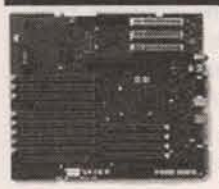

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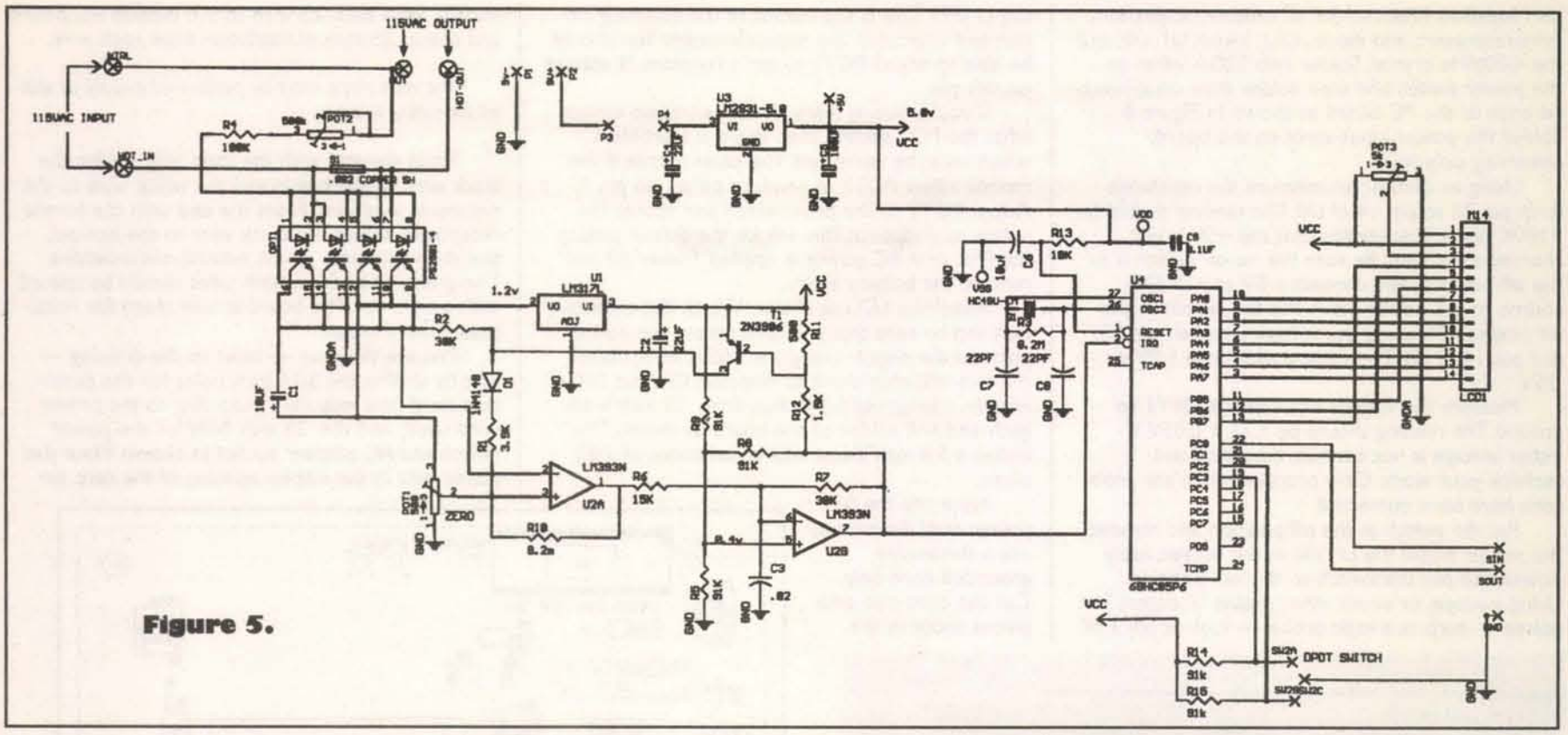


**Figure 5.**

```
        Start clock
One_second_loop
        Wait on clock for 10 "tics"
        (One second total time)
        Get accumulated one-watt/
        second
        pulses
        Write to display
        Add to accumulated watt/
        seconds
        Convert to watt hours
        Write to display
        Output watts and watt-hours
        to serial port
        branch to main
```

This is a simple structure and programmers should always strive to keep program structures simple. When the program structure is too complex, then the structure should be decomposed to keep each element of your design simple.

## LCD I/F Routines

The following LCD initialization was taken from the Optrex LCD data sheet.

Initialization:

set RS and R/W to logic 0
data = 38h for 4ms
data = 0fh for 500ns
data = 38h for 4ms
data = 01h for 500ns
data = 38h for 4ms
data = 06h for 500ns

The display should be cleared with the cursor in the far left position. To send characters to the display, set 'RS' to logic '1' then send the ASCII code for the character. The cursor will automatically increment to the next position, but only for the first eight locations. This is because the 16x1 uses the following memory map:

80:81:82:83:84:85:86:87:C0:C1:C2:C3:C4:C5:C6:C7

The cursor starts out on address 80, increments to 81,82,83. etc. When the cursor is in position 87, it will increment to 88, not C0. So you must keep track of the current cursor position in software and change the internal character address for positions 9-16. Listing 1 is an example of this function. Routines for writing data and control words to the LCD are PUT_DATA and PUT_CTRL. For the control words, the app note instructs us to perform the following sequence:

1. Set R/W = 0 to write to the LCD.
2. Set RS = 0, for an instruction byte.
3. Place data on DB0-DB7.
4. Toggle EN (low-high-low).

Data is latched on the falling edge of EN. Two types of control instructions require extra delay time between the writing of the command and writing data to be displayed. The DMC-16207 supports the instructions shown in Listing 2. These routines were taken from the Motorola HC05 Applications guide. These are the same routines that are used in the Watts Showing.

## Timer Routines

Obviously, a watt hour accumulation cannot be accurately made without an internal clock. For the digital watt meter, we use a clock that 'ticks' at 10Hz, for a resolution of 0.1sec. This is accomplished by utilizing the internal 16-bit programmable timer of the 68HC705. A complete description of this timer is found in the MC68HC705P6 data book and the Motorola HC05 applications guide, both available from Motorola. Listing 3 demonstrates how to set up a 100mS loop for timekeeping. The basic form of this routine is taken from the HC05 applications guide.

## Building and Testing the Watts Showing

I like the build a little, test a little approach, starting with the printed circuit board. Install and solder all the IC sockets, observing the proper

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pin1 location. Next, solder all resistors, capacitors, potentiometers, and diode, CR1. Install U1, U2, and the 4.00MHz crystal. Solder two 22GA wires to the power switch and then solder their unconnected ends to the PC board as shown in Figure 8. Solder the power input wires to the board, observing polarity.

Using an ohmmeter, measure the resistance form pin 28 to pin 14 of U4. The reading should be >100K ohms. This verifies that the +5V is not shorted to ground. Be sure the on-off switch is in the off position, and connect a 6V to 12V DC source to the power input. Put the switch in the on position. Measure the voltage between pin 28 and pin 14 of U4. The voltage should be 5.0V ± .25V.

Measure the voltage from pin 10, OPT1 to ground. The reading should be 1.22 ± 0.05V. If either voltage is not correct, then stop and recheck your work. Only proceed when any problems have been corrected.

Put the switch in the off position and remove the power. Install the LM393 in the socket, apply power, and put the switch to the 'on' position. Using a scope, or some other means to detect fast pulses — such as a logic probe — look at pin 7 of the LM393. This is the output of the summing circuit and interrupts the microcontroller. You should be able to adjust POT2 to get a constant hi voltage on this pin.

If you're seeing many 400uS pulses no matter what the POT setting, then there is a problem which must be corrected. The same is true if you cannot adjust POT2 to produce pulses on pin 7. Adjust POT2 to the point which just causes the pulses to disappear. This will be the default setting the first time AC power is applied. Power off and remove the battery again.

Install the LCD as shown. Watch the orientation and be sure that it is level across the entire plane of the display. Using the 16GA wire, make the two milliohm shunt as directed. Cut the 16GA wire to a length of 6.3 inches. Strip .25 inch from each end and solder to the board as shown. This makes a 5.8 inch shunt with a resistance of .002 ohms.

Now add the AC power cord. Be sure to use a three-wire grounded cord only. Cut the cord into two pieces about in the middle. Strip back 2.5 inch of the outside insulation and about .25 inch of insulation from each wire.

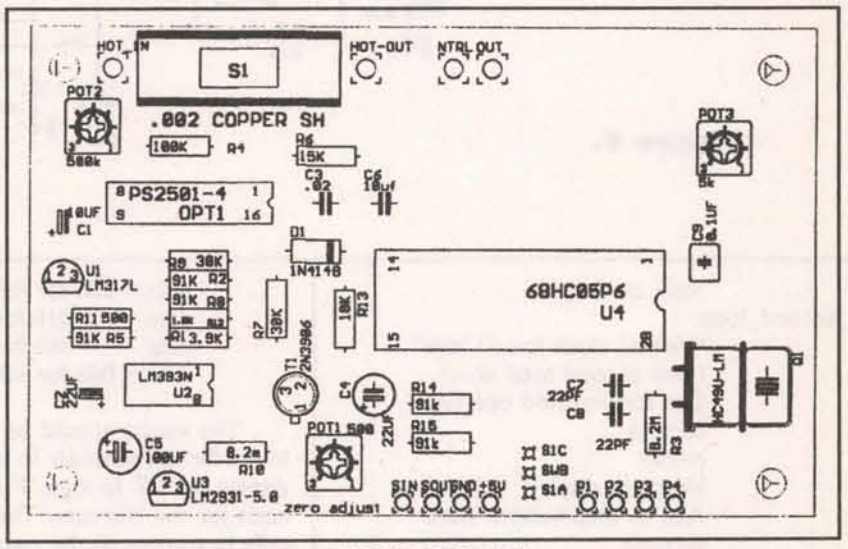
*The next steps must be performed exactly as stated for safety reasons.*

From the end with the male plug, solder the black wire to the hot-in and the white wire to the neutral-in locations. From the end with the female receptacle, solder the black wire to the hot-out and the white wire to the neutral-out locations. The green wires from both sides should be spliced with a wire nut. The board is now ready for installation into the case.

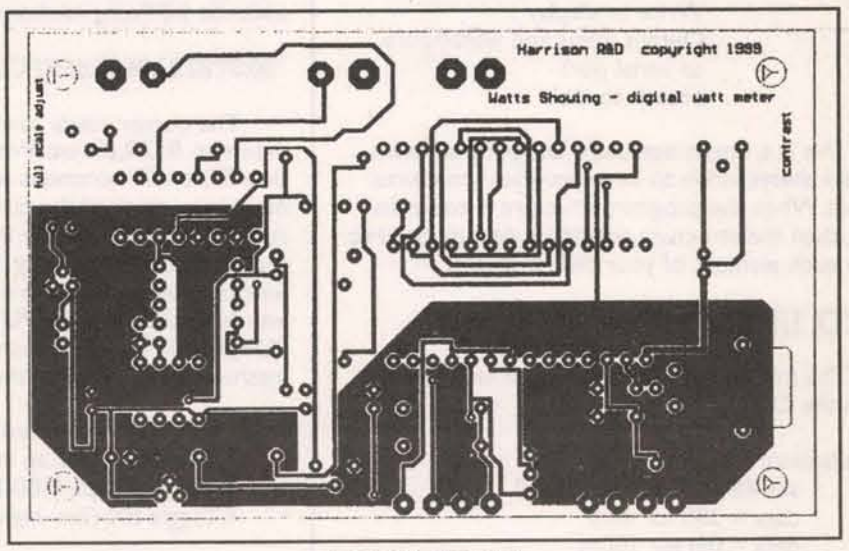
Prepare the case — refer to the drawing — first by drilling the 5/16 inch holes for the extension cord (this may vary according to the power cord used) and the .25 inch hole for the power switch and AC adapter socket as shown. Place the plastic lens in the display opening of the case, on

```
Code  Instruction
-----------------------------------------------------
01H   Clear display
38H   Set 8-bit data, 2-line display, 5x7 font
02H   Cursor to home position
06H   Increment cursor, do not shift display
0CH   Display on, cursor off, blink off
80H   Move to beginning of line 1
C0H   Move to beginning of line 2
*************************************************************
* PUT_CTRL - Write control word to LCD peripheral           *
*        Enter with control word in accumulator             *
*        Return with original value of X                    *
*        Delay ~4.5mS if A=$01 or $02 else delay ~120µS     *
*************************************************************
PUT_CTRL
        STX     TEMPX   ;Save X
        STA     PORTA   ;Write control word to LCD
        BCLR    7,PORTB ;RW->0 WRITE ENABLE
        BCLR    6,PORTB ;RS->0 SELECT COMMAND
        BSET    5,PORTB ;E->1
        BCLR    5,PORTB ;E->0
        LDX     #40     ;20*6~*1µS/~=120µS
L120U
        DECX            ;Delay loop ~120µS
        BNE     L120U   ;20-19,19-18...1-0
        CMP     #$02    ;Commands $01 & $02 req extra delay
        BHI     ARN5M   ;If command > $02 skip long delay
L5M
        JSR     ANRTS   ;JSR+RTS TAKES 12~ (just want delay)
        DECX            ;TAKES 3~ (X=0->1 on first pass)
        BNE     L5M     ;3~ Loop 256*18~*1µS/~=4.608mS Delay
ARN5M   LDX     TEMPX   ;Restore X

ANRTS   NOP
        NOP
        NOP
        NOP
        RTS             ;** RETURN **

*************************************************************
* PUT_LCD - Write data word to LCD peripheral               *
*        Enter with data word in accumulator                *
*        Return with original values of X & A               *
*        Delay ~120µS after data write                      *
*************************************************************
PUT_LCD
        STX     TEMPX   ;Save X
        STA     TEMPA   ;Save A
        STA     PORTA   ;Write data word to LCD
        BSET    6,PORTB ;RS->1
        BSET    5,PORTB ;E->1
        BCLR    5,PORTB ;E->0
        BCLR    6,PORTB ;RS->0
        LDX     #40     ;20*6~*1µS/~=120µS
L120    DECX            ;Delay loop ~120µS
        BNE     L120    ;20-19,19-18...1-0
        LDA     TEMPA   ;Restore A
        LDX     TEMPX   ;Restore X
        RTS             ;** RETURN **
```

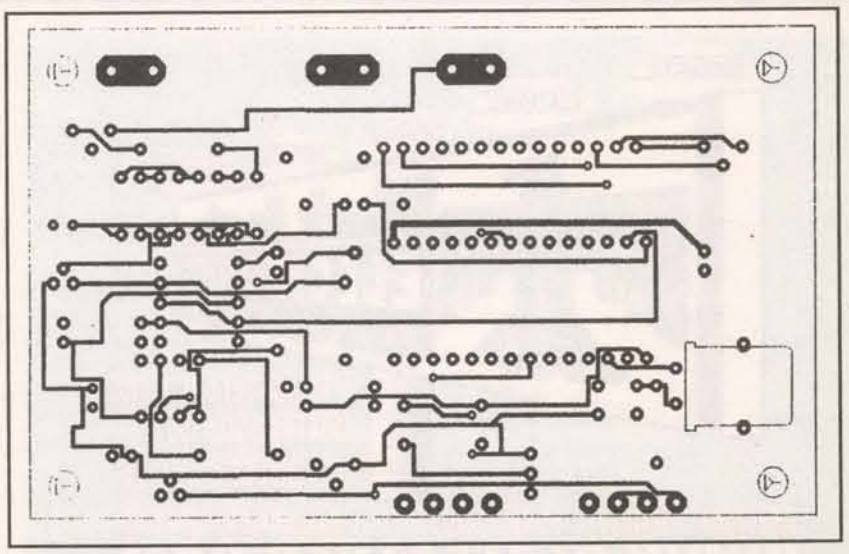
**Listing 2. Put_CTRL & Put_LCD**




**SILKSCREEN**




**TOP LAYER**



**BOTTOM LAYER**

the inside. Using the four .125 inch spacers and four #4 screws provided, mount the PCB assembly into the top half of the case with the LCD pressed against the plastic lens, install the power switch, and the power receptacle into the case. Install the pre-programmed MC68HC705 into the socket. Be sure to observe pin 1. *Installing the chip backwards will result in its destruction.* Make sure the power switch is in the off position and plug in the wall transformer.

Put the switch in the on position and the display should read 000W-0000WH. Use POT3 to set the LCD contrast to your liking. NOTE: You may not have all 000s in the Watts display because it has not been calibrated yet. Don't worry, yet. Use POT2 to zero the Watts display. If it won't zero out, then worry.

At this point, it's time to connect Watts Showing to 120VAC. With the top half of the case laying face down — so the PCB is facing up — plug the power cord into a convenient outlet.

**SAFETY NOTICE:** There is 120VAC on the circuit board, so please use *extreme* caution. Use an AC voltmeter to measure the potential of the PCB ground to AC ground on an outlet. There should be no more than a few volts differential. If you read over 20VAC, then your circuit is not isolated and MUST be fixed before continuing. In some cases, a 'ghost' voltage reading of more than 20VAC could exist. To know if it's real, put a 100k resistor across PCB ground and AC ground and apply AC power. If it's a 'ghost' voltage, then it will drop to near zero VAC. If the voltage holds, it's real.

Disconnect AC power and connect a scope to the anode end of D1. Reconnect AC power and adjust POT2 up and down, using an insulated screwdriver, to a point where the pulses just stop. Now connect a 60W light bulb to the output cord. Turn on the light and the pulses should reappear on the anode of D1. Turn the light off and stand up the case so that the LCD is visible, and also with POT1 and POT2 accessible.

Turn the light on and adjust POT1 for a Watt reading of 60 ± 1 watts. Reset the zero point again by turning off the light and adjusting POT2 to the point at which the Watts display just goes to a 000 reading. Turn the light back on and readjust POT1 for 60 ± 1 watts. This time when the light is turned off, POT2 won't require much adjustment, if any, to reach the point of just zeroing the Watts display.

Try to keep any breeze away from the opto-isolator when calibrating. The stacked differential pairs are extremely sensitive to temperature gradients across the part. It will be impossible to properly calibrate if air currents are moving across U1.

Let the unit sit with power on for about 10 minutes and do one more series of adjustments for a final calibration. Keep in mind the thermal sensitivity of the opto-coupler and be sure it's shielded from air currents or direct incandescent light which might warm the part.

Turn off Watts Showing and unplug it from the 120VAC outlet. Put the strain relief's on the power cords and put both halves of the case together around each strain relief. Use the four screws to tighten the case halves and you're done.

```
*****************************************************
*  Beginning of main timing loop                    *
*       Loop is executed once every 10mS (exactly)  *
*       A pass through all major task routines takes*
*       less than 10mS and then time is wasted until*
*       the output compare flag gets set (every 100mS).
*       When an output compare triggers, the flag is*
*       cleared & 50000 is added to the compare reg *
*       so the next trigger will occur in exactly 100mS
*       (50000*2µS/cnt = 10mS).                     *
*                                                   *
*       The variable TIC keeps track of 100mS periods
*       when TIC increments from 9 to 10 it is cleared
*       to 0 and seconds are incremented.           *
*                                                   *
*****************************************************
MAIN1
        BRCLR   6,TSR,MAIN1 ;Loop here till OCF flag set
        LDA     OCMP+1 ;Low byte of OC register
        ADD     #$88    ;Low half of 50000
        STA     TEMPA   ;Save till high half calculated
        LDA     OCMP    ;High byte of OC register
        ADC     #$13    ;High half of 50000 (+carry)
        STA     OCMP    ;Update OC reg
        LDA     TEMPA   ;et low half of updated value
        STA     OCMP+1 ;Update low half of OC reg
* OC now = old OC + 50000, and OCF flag is clear
        LDA     TIC     ;Get current TIC value
        INCA            ;TIC=TIC+1
        STA     TIC     ;Update TIC
        CMP     #10T    ;10th TIC ?
        BLO     ARNC1   ;If not, skip next clear
        CLR     TIC     ;Clear TIC on 10th
ARNC1   EQU     *
* End of synchronization to 10mS TIC; Run main tasks and
* branch back to main within 100mS. Sync OK as long as
* no 2 consecutive passes take more than 200mS.
```

**Listing 3. 10Ms Timing Routine**

## Using Watts Showing

You can use Watts Showing to collect data on energy usage costs for appliances around your home or office or make sure that a power-strip's ratings won't be exceeded by all of the devices plugged into it. Take a freezer, for example. A typical household freezer will require 200-400 watts when the compressor is running. But the compressor only runs when its inside temperature exceeds the thermostatically-controlled value. At any given time, it may or may not be running. If you connect the freezer to 120VAC through Watts Showing, and let it run for a day, you can see the total watt hours accumulated over time. After allowing it to run for 24 hours, you can multiply the watt-hours accumulated by your local power provider's rate to get cost-per-day of freezer operation.

Electric rates average about $0.085 per kilowatt hour in the U.S. If your freezer used 2000 W/hr a day, the cost would be $.17 or $5.10 per month. Of course, the duty cycle will vary with the amount of insulation in the freezer and the ambient temperature where the freezer is located.

Finally, I would like to thank Steve Woodward for his design of the modified Gilbert Cell power measurement circuit. **NV**

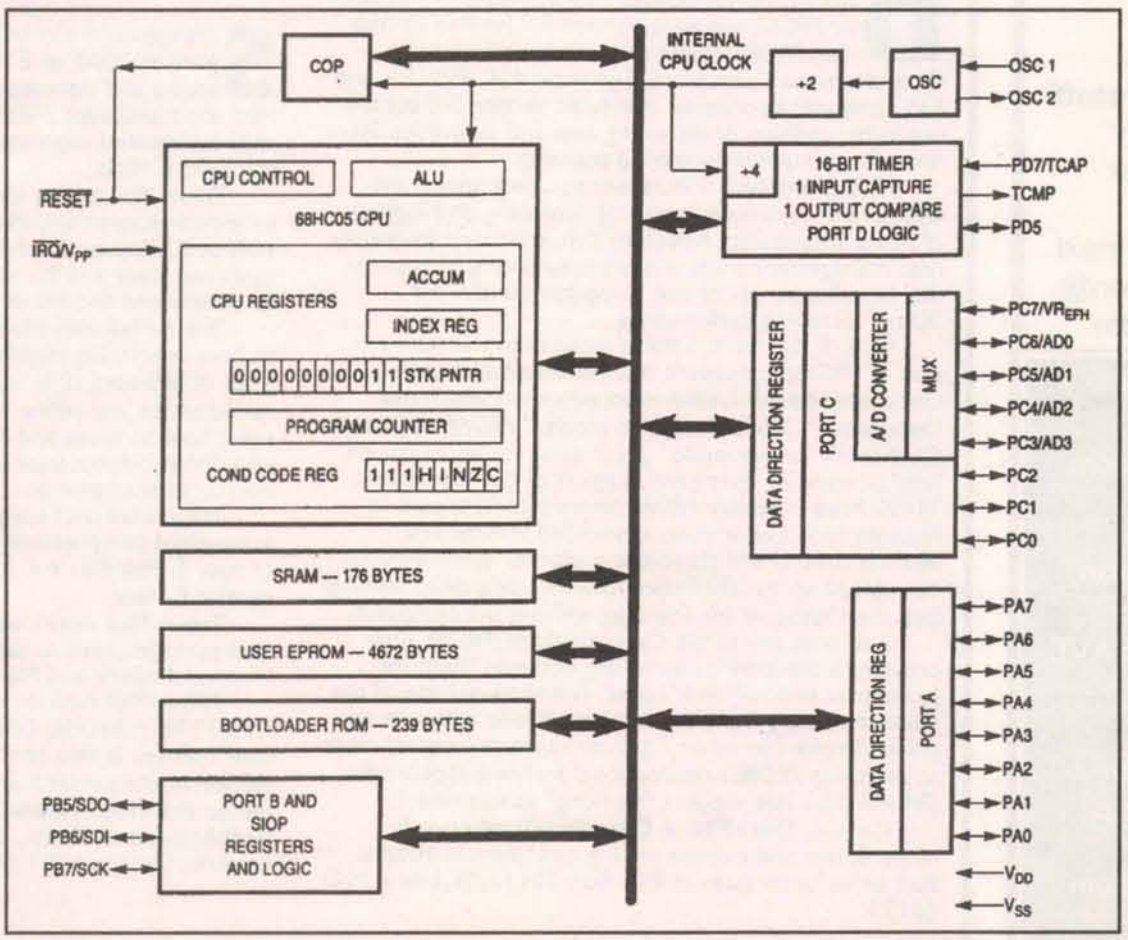



**Figure 6 — MC68HC705P6 block diagram.**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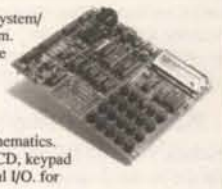

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